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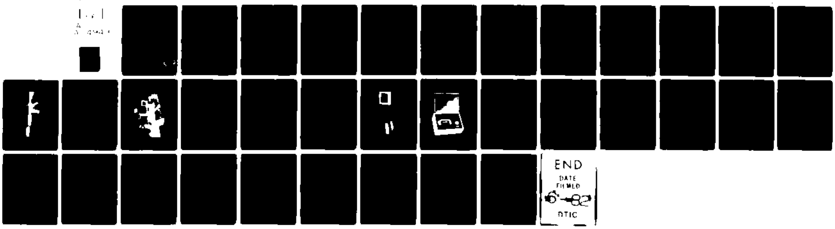

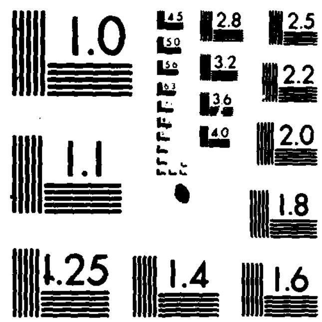
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# THEATER NUCLEAR FORCE SURVIVABILITY, SECURITY AND SAFETY INSTRUMENTATION

## Volume II - Engineering Development Phase — Fiscal Year 1981

BDM Corporation
P.O. Box 9274
Albuquerque, New Mexico 87119

30 June 1981

Final Report for Period 15 January 1981—30 June 1981

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the status of the engineering development phase of the TNFS3 Instrumentation Development effort. Evaluation of TNFS3 technologies, hardware, and concepts required field testing in both controlled test environments and simulated tactical environments. Free-play, force-on-force testing, and real-time casualty assessment provide the two-sided, free-flowing operational scenarios necessary to determine successfully the resolution of the majority of the TNFS3 issues.

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# PREFACE

This report was prepared by The BDM Corporation, Technology Applications Center, P. O. Box 9274, Albuquerque, New Mexico 87119 under the Defense Nuclear Agency contract DNA001-80-C-0083. Captain S. W. Achromowicz is the Contracting Officer's Representative.

This report presents the status of the Engineering Development phase for the TNF $S^3$ Instrumentation Development effort. This instrumentation is needed to satisfy the test analysis and evaluation requirements on force-on-force, free-play testing of the TNF $S^3$ using real-time casualty assessment. The instrumentation design philosophy centered around a system that is to be modular, flexible, and expandable. The instrumentation will be portable, will not require extensive field support, and in some cases will be secure from outside monitoring. Existing off-the-shelf technology is being used to minimize development risk.

The instrumentation system consists of three basic elements. The master station performs the operations and maintenance, calibration, test control, and data quick-look tasks. The RF communications system allows for two-way communications from the master station via repeaters to the players, and will evolve into an accurate transponder position location subsystem. The player instrumentation contains a microcomputer and will be capable of totally decentralized operations. It will perform the functions of position location, weapon simulation (weapon and target sensors), player cueing, data logging, RF communications with the master station, and the computation of real-time casualty assessments.

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SUMMARY OF ACCOMPLISHMENTS
FOR THE PERIOD
15 JANUARY 1981 THROUGH 30 JUNE 1981

## 1 INTRODUCTION.

This report summarizes the tasks accomplished on the TNFS$^3$ instrumentation development for the period of 15 January, 1981 through 30 June, 1981. It is not intended to be a stand-alone document, but supplements the Theater Nuclear Force Survivability, Security and Safety Instrumentation - Final Report "Engineering Development Phase - Fiscal Year 1980" dated 31 December, 1980. This effort was reduced in scope due to limited funding and the effort was limited to system base testing, development of an expanded Player Initializer to replace the master station, implementation of the executive control system operating system software on the Phase II microcomputer, and the development of a simplified position-location algorithm, and real-time casualty assessment capability. All of the above objectives were met and a great deal of effort was expended to correct deficient government-furnished equipments, namely the weapons effects subsystems.

## 2 SYSTEM LEVEL TESTING.

The system-level tests were initially planned to take place at the DNA ARES facility but were performed in the open area behind the BDM R&D Laboratory for reasons of convenience and cost effectiveness. Testing was conducted on the following subsystems.

(a) RF transceiver characterization.

(b) Player to transponder ranging evaluation.

(c) RF communications evaluation.

(d) Weapons effects subsystem evaluation.

## 2.1 RF Transceiver Characterization.

The RF transceiver tests were conducted to verify the operation of the government-furnished RF units produced by VEGA Precision Laboratories, Vienna, Virginia. The tests evaluated the unit-to-unit variance of RF transceivers over a known range. Signal amplitude measurements were taken for three antenna orientations (vertical, horizontal, and axial) for the Player Pack systems which use a vertical antenna to the omni-directional antenna used at the repeater/transponder towers. These data allowed the generation of range correction tables for use in the Player Packs. The plot of the range-versus-amplitude corrections are shown in Figure 1.

The RF units were also tested for sensitivity and false alarm rates. The results of these tests indicated that a minor modification was needed to the receive inhibit during the transponder position-location mode. This was accomplished by using existing signals within the RF unit's digital board. The sensitivity was also evaluated and all of the units have been set to approximately -65 dBm. This setting proved to be satisfactory to optimize the maximum range and had an extremely low false alarm rate.

## 2.2 Player to Transponder Ranging Evaluation.

These tests were performed in early June. A four-transponder network, Player Initializer, and two players were tested individually. The transponders were placed in a 40-by-70-meter grid and the Player Pack was positioned relative to the grid. The Player Initializer controlled the test and performed the following functions:

(a) Request player event data - every 2 seconds.

(b) Request player group to "get ready" to do position location - every 10 seconds.

(c) Request player group to "do" position location - every 10 seconds.

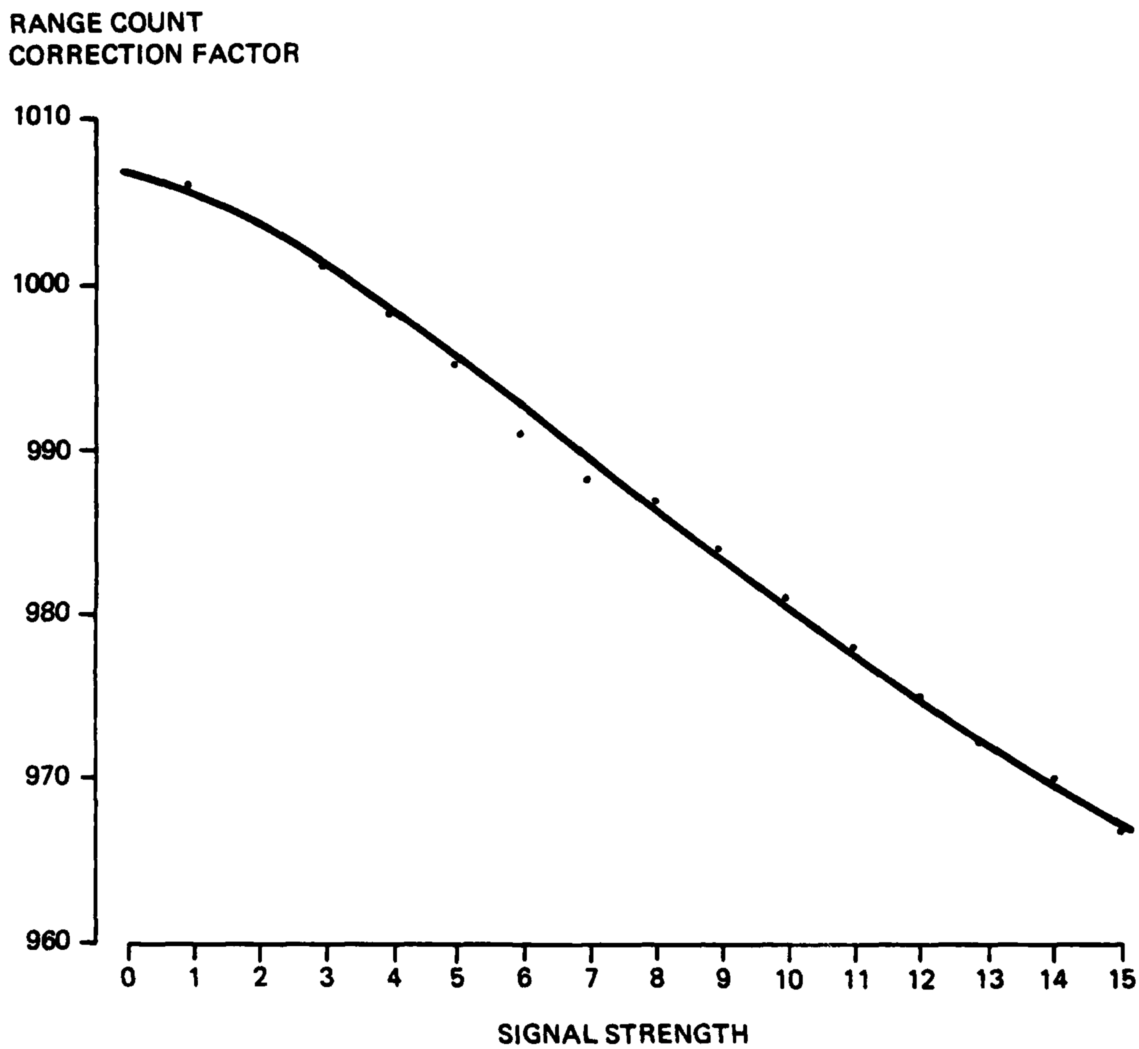


Figure 1. Range count correction for signal strength

(d) Display player operational status on cathode ray tube (CRT) #1 - every 5 seconds.

(e) Display player status on CRT #2 or print on Silent 700 - when events are available.

Preliminary results showed that successive ranging measurements from a stationary Player Pack to a transponder were within $\pm 3$ meters and most often $\pm 2$ meters, and that the Player Pack is capable of accurate ranging through a 40-foot, performed (with stressed rebar) concrete building. This test setup will be used to evaluate the actual performance of the transponder position-location subsystem and the position-location algorithm during the proposed follow-on effort. The Player Pack communicated directly with the Player Initializer which utilized an identical tower arrangement.

## 2.3 RF Communications Evaluation.

The RF communications evaluation consisted of sending and receiving messages to and from a Player Pack and Player Initializer under various conditions. The communications protocol was as follows:

(a) The Player Initializer sends a "request event message" to a specific Player Pack (each Player Pack is assigned a unique ID number).

(b) The Player Pack decodes the request and, if it was for that Player Pack, responds with either a "no event" or a "position-location event" if that has occurred.

(c) If the Player Initializer does not receive a return message, it sets a "no RF communications" flag in that player's status display and attempts to call up to three more times. If a message is received the Player Initializer removes the flag and sends a "message received" to the specific Player Pack. The Player Pack then removes the message from his transmit buffer and stores it in memory.

This testing was an excellent exercise of both the Player Initializer and the Player Packs as it demonstrated the possibility of missing RF messages on the first or second try due to external RF emissions, improper sensitivity setting, and antenna positioning, without actually losing any data. Additional testing is planned to determine maximum range and range through trees and foliage during the follow-on effort.

2.4 Weapons Effects Subsystems.

Testing and checkout of the GFE weapons effects subsystems consumed a great deal of the total effort because of unreliable cabling and electronics in all of the elements except the rifle laser. The following subparagraphs describe the activities performed for each element of the weapons effects subsystem.

2.4.1 Pistol Laser. Two 357 magnum handgun lasers were delivered and accepted. One unit was inoperable and was immediately returned. The second was evaluated. It operated on a intermittant basis and would often shoot multiple rounds on a single trigger pull. The unit that was returned to the vendor was not repairable and it was again returned to BDM. BDM undertook the task of determining what could be done with the handgun laser system and concluded that a redesign of the electronics and the packaging was required. This task has been scoped and will be a follow-on effort with the goals of cost reduction, modular design, and high reliability.

2.4.2 Rifle Laser. The M-16 rifle laser was a modification of the MAGLAD training laser and was not designed specifically for TACTICS. The laser contains many discrete components, is expensive, and is considered too large. The basic circuitry has been reviewed and a redesign using telescope optics has been scoped. The goals of the redesign are to contain identical modules as the 357 handgun and to remove as much of the electronics as possible from the laser and place them on the Player Pack interface printed circuit board. Many of the difficulties encountered while testing the rifle lasers concerned the lack of appropriate test equipment to determine beam divergence and laser intensity. An optical bench has been identified and the above measurements will be easily performed in the follow-on effort.

The model M-16 assault rifles were modified to use the trigger pull to activate a reed switch as a fire event rather than the muzzle flash. Four additional M-16 assault rifles were backordered and the CAR-15 assault rifle was substituted. They have been modified and are shown in Figure 2.

2.4.3 Weapons Effects Communications Interface Unit. The circuitry of the GFE WE CIUs required major modification. A buffer integrated circuit was added to correct a problem with the multiple body sensor latch, eight of the data lines had to be reversed, and several diodes were added to the units. The function of the WE CIU was evaluated and it was recommended that a new unit be designed in conjunction with the laser systems. This design will optimize and centralize the electronics on the CIU card and remove many of the functions now being done on the weapon or laser. It is estimated that the redesign will reduce the cost of production WE CIUs by 50 percent or more.

2.4.4 Weapons Effects Harness and Sensors. After several months of use, a number of design deficiencies have been identified concerning the weapons effects harness, cloth material, and sensors. The cable presently utilized is difficult to work with and difficult to repair. The routing of the cables must be human engineered and a positive locking connector is required. The vest area sensors should be slightly enlarged to cover the side of rib cage and a more realistic material, such as standard camouflage material, should be used if possible. Earlier studies showed that the dark green and black coloring of the standard issue camouflage material did not allow sufficient energy for the fiber optic area sensor

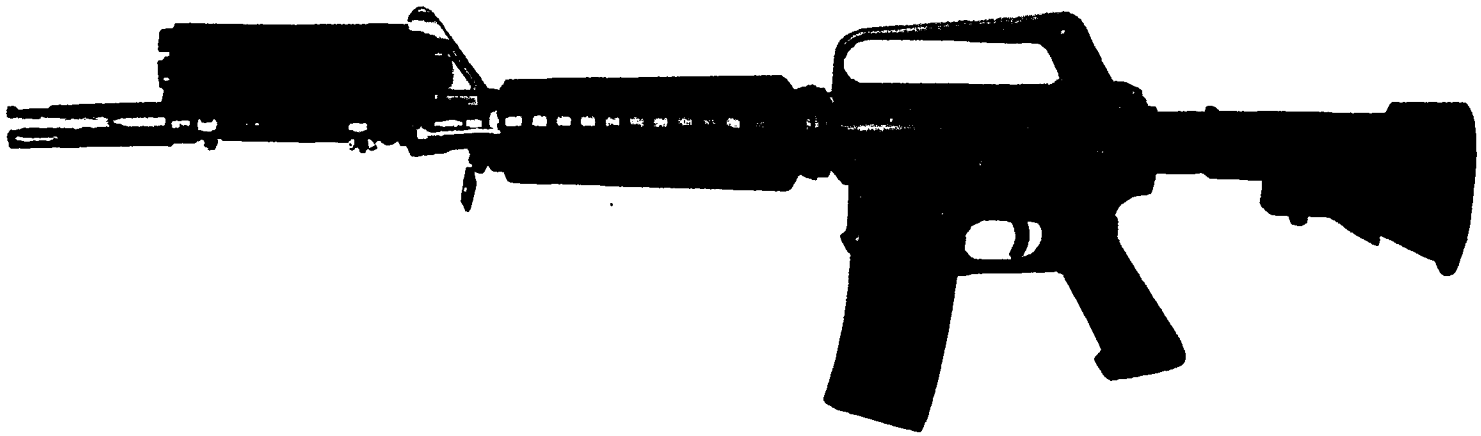

Figure 2. CAR-15 rifle with laser and palm interface.

to detect the laser message. Since that time, however, advances have been made in photo cell sensors and it is estimated that a 10 to 20 decibel gain in the sensor system can be achieved. This evaluation and design of ruggedized, high-gain sensor has been scoped and will be addressed in the follow-on effort.

## 3 PLAYER INITIALIZER DEVELOPMENT.

The Player Initializer was initially conceived as a support element and was to be used to assign identification numbers to the Player Packs and perform an in-the-field checkout of all of the Player Pack elements. Because of limited funding, subsets of the command, control, communications, display, and recording functions planned for the master station were programmed into the Player Initializer. The present Player Initializer is not intended to replace the master station, but to be a small-scale unit that can adequately handle up to 20 or 25 players in real time. The elements of a full-up Player Initializer are shown in Figure 3.

The Player Initializer was constructed using two of the standard TACTICS card cages and interconnecting them to obtain the additional peripheral slots necessary for interfacing to the CRTs and printer.

The Phase II microcomputer was programmed using two EPROM cards to act as the test controller, display driver, and data recorder. A high-capacity gell cell powers the TACTICS microcomputer and the associated peripherals, whereas the CRTs and APPLE display unit use commercial 60 Hz 115 volt ac.

### 3.1 Player Initializer Alphanumeric Display Subsystem.

The Player Initializer was designed to drive two types of alphanumeric displays. The first is two CRTs which display the status of the red and blue teams and are updated every 10 seconds. Only the data that change are updated and the CRT remains almost flicker free. The format for the event display is shown in Figure 4 and the format for the

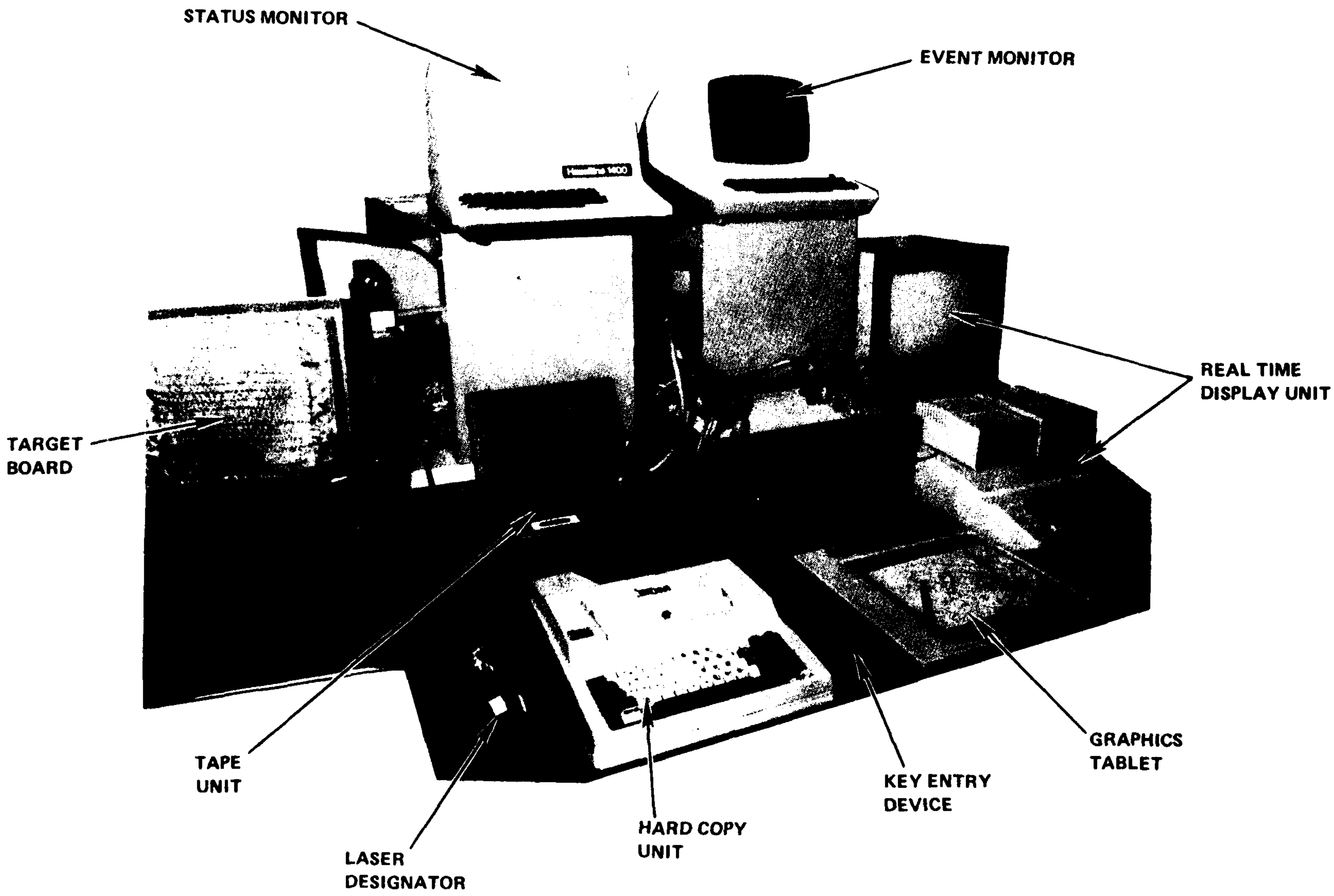


Figure 3. Player initializer units.

| TIME | EVENT | PLAYER FIRER | POSTURE WPH | ROUND | PLAYER TARGET | POSTURE LOCATION |
|---|---|---|---|---|---|---|
| 02:54:53 | FIRE | 01 | Upright M-16 | 1 | | |
| 02:54:53 | HIT | 01 | Upright M-16 | 1 | 02 | Upright Back, Area |
| 02:54:53 | FIRE | 02 | Upright M-16 | 1 | | |
| 02:54:54 | FIRE | 01 | Upright M-16 | 2 | | |
| 02:54:56 | FIRE | 02 | Upright M-16 | 2 | | |
| 02:54:59 | FIRE | 02 | Upright M-16 | 3 | | |
| 02:55:00 | FIRE | 02 | Upright M-16 | 4 | | |
| 02:55:07 | FIRE | 02 | Prone M-16 | 5 | | |
| 02:55:08 | FIRE | 02 | Prone M-16 | 6 | | |
| 02:55:16 | FIRE | 01 | Upright M-16 | 8 | | |
| 02:55:17 | FIRE | 02 | Upright M-16 | 7 | | |
| 02:55:17 | FIRE | 01 | Upright M-16 | 4 | | |
| 02:55:17 | FIRE | 02 | Upright M-16 | 6 | | |
| 02:55:17 | FIRE | 01 | Upright M-16 | 5 | | |
| 02:55:18 | FIRE | 02 | Upright M-16 | 4 | | |
| 02:55:25 | FIRE | 02 | Upright M-16 | 10 | | |
| 02:55:25 | HIT | 02 | Upright M-16 | 10 | 01 | Upright Head |
| 02:55:26 | FIRE | 02 | Upright M-16 | 11 | | |
| 02:55:26 | HIT | 02 | Upright M-16 | 11 | 01 | Upright Head |

Figure 4. Event display format

status display is shown in Figure 5. The second alphanumeric display channel is a hard copy unit. As shown in Figure 3, a Texas Instruments Suitcase Silent 700 terminal can be used. This unit writes 30 characters per second and is used to list key events only. The final alphanumeric input/output device is the Key Entry Display Unit (KENDU). It was designed to be used with the basic Player Initializer when no other display device was available or needed (such as during a small test or pretest scenario evaluation.) The KENDU can also be interfaced to a standard Player Pack for use by an umpire to enter key events and observations. The operation of the Player Initializer can originate from any one of the CRTs, the Silent 700, or the KENDU.

### 3.2 Player Initializer Color Display System.

The color display system consists of an APPLE II microcomputer with a color monitor, a graphics tablet, and two floppy disks. The system, as shown in Figure 6, can display the x and y position of the red and blue forces and the graphics tablet is used to draw the key features of the test area. The present system can update up to 3 players a second and could handle up to 10 without a great deal of flicker. A "scoreboard" of the red and blue team wounded and killed appears at the bottom of the display. Players are identified by numbers. A red or blue bar above the number designates the team and a red or yellow bar below indicates wounded or killed.

### 3.3 Player Initializer Tape Recorder Subsystem.

The Player Initializer tape recorder system will record the status records as they are collected, allowing the test scenario to be replayed for analysis and for immediate feedback during the after-action review. This unit, the MFE Model 250B, shown in Figure 7, can record up to 128K bytes of data on a single cassette tape. Its control card was wite wrapped and the unit was functionally tested. The final device service routine and task software has not been completed.

```
         POSITION                                 ROUNDS AMMO                      STATE HARDWARE

ID  ---X--  ---Y--  ---Z--      D/A    WOUNDS     FIRED    OUT    MKS      DAPLEQHF  T...PRLD
     Team 1
1       0       0       0      Alive     0          0       N      4       01100000  10000100
2                       0
3                       0

     Team 2
4                       0
5                       0
6                       0

Today is June 1, 1981  18:54:31  ET = 0:0:16:47
```

| State Bits | Name | Significance if Set |
|---|---|---|
| D | Dead | Player is dead |
| A | Ammo | Player is out of ammo |
| P | PLC | PL confidence low |
| L | Log | Data logger full |
| E | Event | Event message pending |
| Q | DRQ | Direct Range cycle request |
| H | HIT | Illuminated since last status poll |
| F | Fired | Find weapon since last status poll |

| Hardware Bits | Name | Significance if Set |
|---|---|---|
| T | TIP | No test in progress |
| P | PLF | PL system failure |
| R | RFF | Radio failure |
| L | LAS | Laser failure |
| D | DET | Detector harness failure |

Figure 5. Status display format

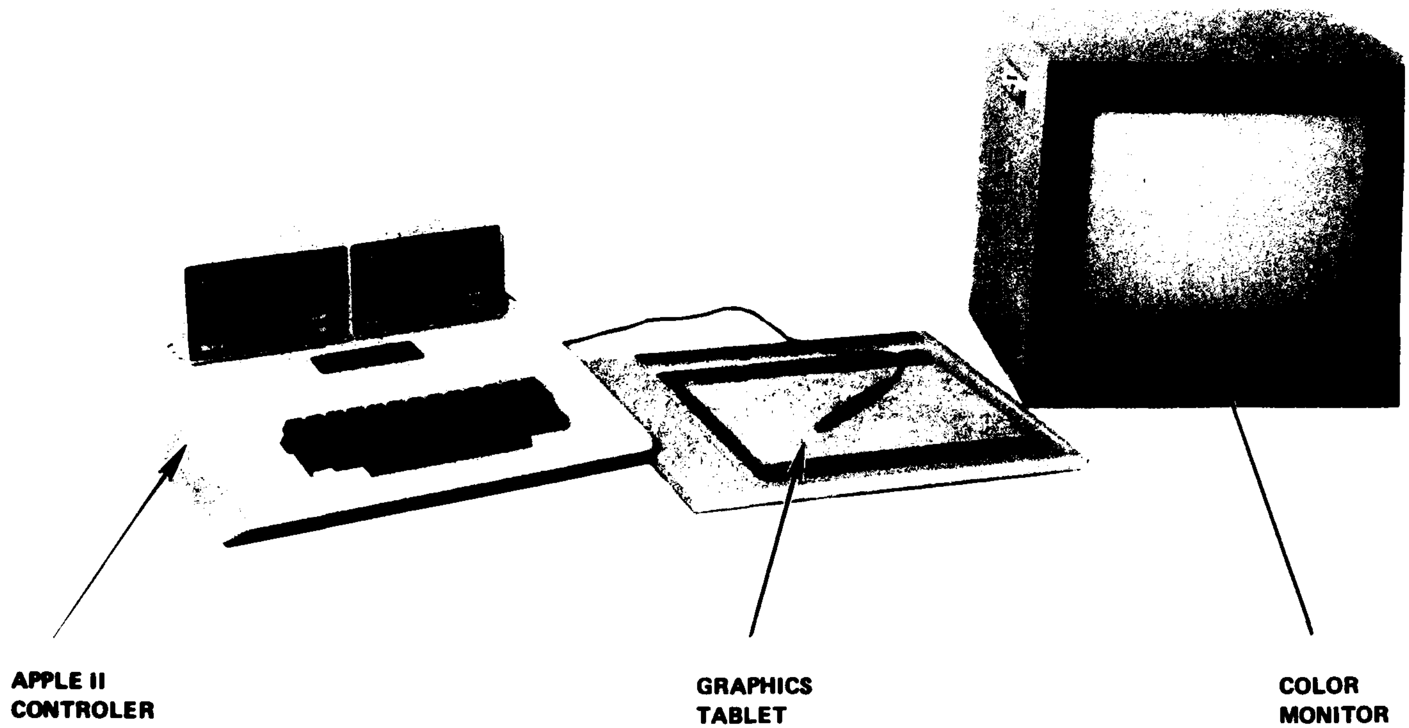


Figure 6.  Apple II real-time display unit.

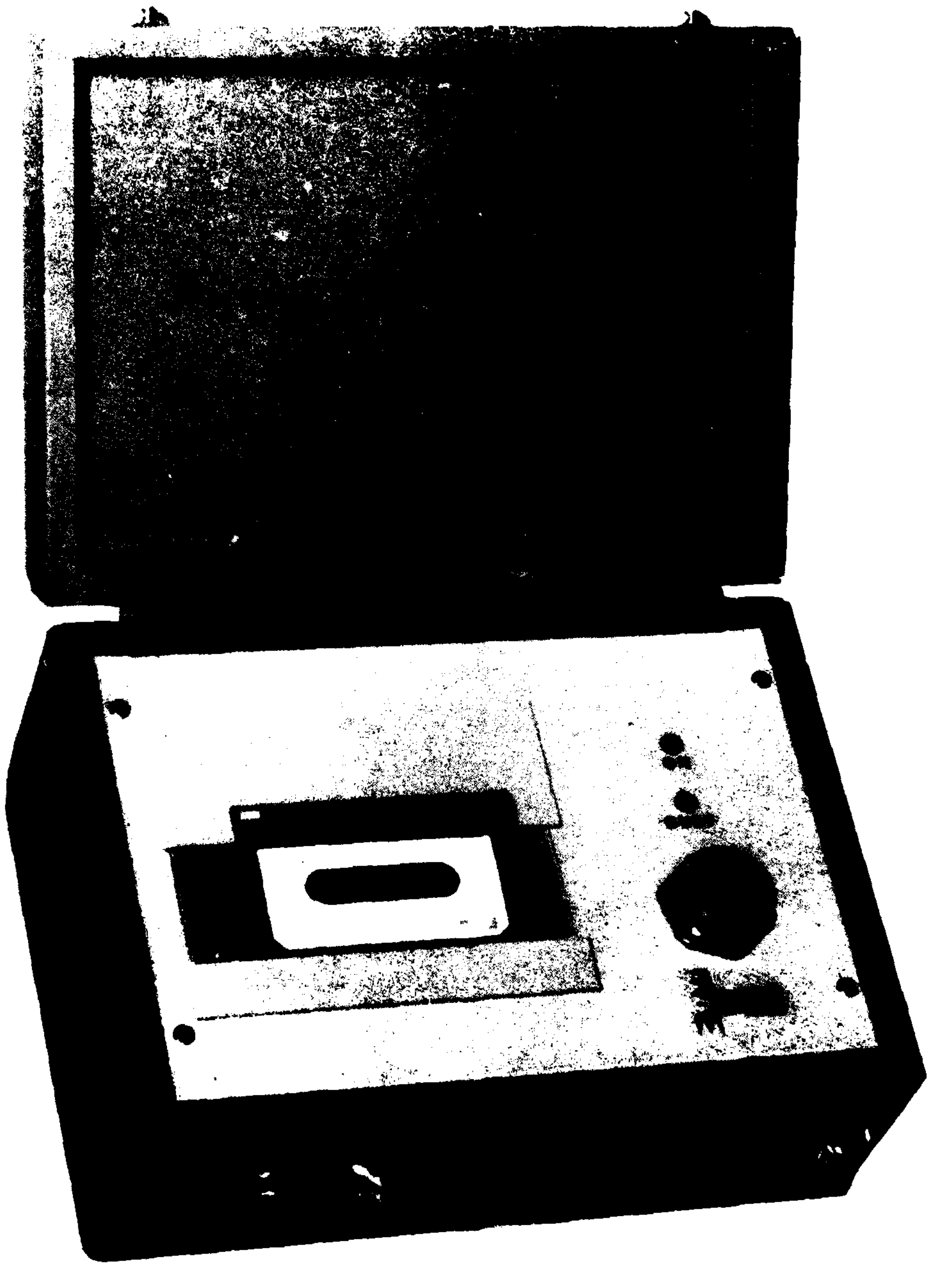

Figure 7. Player initializer tape unit.

## 3.4 Player Initializer Laser Designator and Target Board.

The laser designator is a modified M-16 laser which is hard-wired to the Player Initializer. During player initialization, the operator enters the marksmanship level of the player, and whether or not he is wearing body armor. The system assigns him a unique "ID NUMBER" or identification number. At a later time when the real player has put on his Player Pack and is ready for initialization, the operator enters the Initialize Player (IP) command, enters the ID, and "shoots" the player with a special code containing the ID assigned to the player. The player's Player Pack accepts the ID from the laser message and loads it as his ID. The Player Pack and the entire system can now be checked out using the Display Player Status (DPS) command which displays on the CRT the player's position (x, y, z); alive, dead or wounded, total rounds fired, and the status of all of the subsystem elements.

# 4 EXECUTIVE COMPUTER SYSTEM OPERATING SYSTEM.

## 4.1 Background.

The TACTICS instrumentation must be extremely flexible to handle new and unforeseen applications and to adapt to those applications quickly and inexpensively. The use of a modular structure and a common bus protocol in the hardware reflects this need. Accomodating this requirement in the software structure is not nearly so straightforward, but it has been done. The software is also modularly structured and all modules obey the same set of common protocols, but the structure itself does not solve many of the strictly software-related problems that arise in every event-driven environment. A typical example of this problem is the resource allocation conflict caused by multiple, nearly simultaneous weapon engagements. Here, the player is engaged and the RTCA process is invoked and the second engagement occurs before the previous RTCA has completed. What should be with the second set of engagement data?

Should it: (1) be ignored, (2) preempt the current RTCA, (3) be queued and subsequently processed, or (4) be concurrently processed?

A thorough examination of the impacts on software of an event-driven, rapidly changeable, reliable software structure led to the choice of the operating system concept widely used in commercial minicomputers. Even within this conceptual structure there are many alternative approaches that have been used successfully. The one chosen, however, is the most compatible with all of the conditions and constraints simultaneously: a multi-tasking, multi-user, event-driven, real-time operating system. This provides the software core that controls system timing, resource allocation, process creation and deletion, and all of the actual device control for physical input/output of data. Acquisition and processing of the data are handled by a collection of separate programs or "tasks", which execute under control of the operating system and make "supervisor calls" to OS routines to perform commonly required functions. This approach lumps all coordination, device control, and resource allocation into a single core module which is stable, and all data processing into separate submodules which are easily modified without impacting the operational control functions. This division of software offers a highly reliable, very flexible structure in which changes can be made very rapidly with low risk.

## 4.2 ECS Functional Description.

A complete description of the internal workings of ECS is well beyond the scope of this document and is one of the tasks in the follow-on. What follows is a brief summary.

ECS is a collection of interactive modules which together provide both a stable computer environment and common data management services for the programs which actually process the real-time player-related data. The major modules are the task scheduler, the input/output (I/O) supervisor, the task manager, and the memory manager.

The memory manager maintains the undedicated memory. That is, it is a "bookkeeper" which keeps track of how much and where there is memory in the computer that is not currently in use. Tasks or ECS may request for reuse by another process. The net effect of this module on the overall performance is that the computer "appears" to have much more memory than it actually has.

The task manager is responsible for process creation and deletion and for maintaining the priority queues for the task scheduler. When an event occurs, the task manager is invoked to "create" the process that handles the data for the event. This involves loading a program from EPROM into the location memory allocated by the memory manager, relocating it, and placing the task on the proper priority queue for the scheduler. When the task finishes processing the data, it invokes that task manager to delete the process. This includes removing it from the scheduler queue and releasing the memory it occupies for reuse by other processes. The task manager provides the solution to the resource allocation conflict mentioned earlier: for each separate engagement, a new process (RTCA) is created to handle the data. Thus at any one time there may be several RTCA processes in progress.

The I/O supervisor is invoked by a task whenever data must be transferred via hardware. All I/O requests use exactly the same protocol so that a task may access data from any device without being concerned with the procedure for manipulating the device. The supervisor passes the request to the specific Device Service Routine (DSR) for the specified device and then "suspends" the calling task until the I/O process is complete. Once a task is suspended, the central processing unit (CPU) is available to other processes until the I/O process is complete. This makes maximum use of the CPU to perform other functions.

The task scheduler is invoked every 50 milliseconds by the real-time clock or whenever a task is suspended. Its basic function is to search the priority queues, in order, to find a task awaiting the CPU. When it finds a task, the scheduler resets its clock and passes control of the CPU to the tasks. This assures that all active tasks get CPU time on a regular basis (no "lookout") and that whenever a task is suspended for I/O, the time for I/O is used effectively by executing other tasks.

### 4.3 ECS Status.

ECS was first loaded for execution in February and was debugged and fully tested in April. Since April it has been used continuously with no evident problems. It has been used successfully in both the player configuration and in the Player Initializer.

### 4.4 Task Software.

All tasks, whether in the player or in the Player Initializer, execute under control of, and in conjunction with, ECS. Some of the tasks are common to both, but most are not. In either case the basic operational structure is similar. In the Player Initializer, a keyboard monitor accepts commands from the CRT keyboard and processes them. Figure 8 lists the commands available. In the player a similar module, the RF command interpreter, accepts commands from the Player Initializer via the radio and processes them. In both cases, commands are processed by invoking the task manager to execute a separate task whose sole purpose is to process the specified command. This minimizes the amount of memory allocated to command processing.

### 4.5 Player Tasks.

The set of tasks that constitute a "player" are (1) the RF command interpreter, (2) the position-location algorithm, (3) RTCA, (4) the Player Status Monitor (PMS), and (5) any other tasks required for the particular player application. Of these, only the RF command interpreter

A. Display Commands

DE Display Events
DBS Display Battle Statistics
DPD Display Player Data
DPS Display Player Status
HPA Halt Player Action Plot

B. List Commands

LC List Commands
LT List Teams
LPI List Player Information
LPL List Position Location Groups
LDR List Direct Ranging Groups
LTC List Transponder Coordinates

C. Show Commands

SPS Show Player Status
SDT Show Time and Date

D. Test Commands

Start Start Test
Stop Stop Test

E. Pre-Test Initialization Commands

BPI Build Player Information
DELP Delete Player Information
BT Build Teams
IP Initialize Player

Figure 8. Executive control system commands

| | |
|---|---|
| BPL | Build Position Location Task Set |
| BTS | Build Test Task Set |
| BDR | Build Direct Range Task Set |
| STS | Set Transponder Coordinates |
| SPL | Set Position Location Groups |
| SDR | Set Direct Ranging Groups |
| CTPL | Calibrate Transponder Position Location |
| CPL | Change Position Location Groups |
| CDR | Change Direct Ranging Groups |
| XPL | Start Position Location Cycles |
| XDR | Start Direct Ranging Cycles |
| HPL | Halt Position Location Cycles |
| HDR | Halt Direct Ranging Cycles |
| RA | Reload Ammunition |
| KP | Kill Player |
| RP | Revive Player |
| BIT | Do Built-in-Test |

F. Post-Test Data Recovery

| | |
|---|---|
| UP | Unload Player Data |

G. Miscellaneous Master Station Commands

| | |
|---|---|
| IDT | Initialize Time and Date |
| IPSM | Initialize Player Status |
| RSET | Reset Player Status Monitor |
| LM | List Memory |
| MM | Modify Memory |
| XT | Execute Task |
| KT | Kill Task |
| CRU | Ready Write CRU |
| Q | Quit |

Figure 8. Executive control system commands (Continued)

and the player status monitor are fully implemented. The PSM is implemented as an extended operation (XOP) within the structure of ECS. This makes it globally accessible and memory resident. The operational philosophy of all player software is asynchronous "on demand". That is, as events occur, the event data are queued in an event buffer accessible by the command interpreter. The queing is done by the event processing task via supervisor calls to ECS. The PMS is also invoked by the task to reflect the occurrence of the particular event. When the player receives a "send status" command, the command interpreter reads the status from the PSM and transmits it without examining it in any way and waits for the next command. If the status message indicates that an event message is present, the Player Initializer will issue a "send event" command. On receipt of a "send event" command, the command interpreter will transmit whatever data are in the event buffer without examining it. In this manner, events are sent "on demand" in chronological order. In the case that no "send event" commands are received by the player for whatever reason, all of the events are still resident in the event buffer at the end of the test and can be retrieved at that time. The event buffer can grow as needed to hold event data limited only by the total amount of memory available in the Player Pack. This "demand mode" of operation assures that the maximum amount of both CPU time and system memory is always available for use in processing real-time test-related data.

## 4.6 Player Initializer Tasks.

The Player Initializer contains many more tasks than were originally anticipated due to cancellation of funding for the master station. The operational philosophy is similar to that of the player. Each function is performed by a separate, small, simple task and the coordination of these tasks produces the overall results. Test operation can be visualized as a set of foreground tasks (status display, event lists, etc.) and background tasks (PL coordination, event data transfers, etc.) which occur at regular intervals with no human intervention.

## 5 DEVELOPMENT OF A SIMPLIFIED TRANSPONDER POSITION LOCATION ALGORITHM.

Traditionally, this problem has been solved using large computers and Kalman filters. Various attempts at using classical least squares techniques met with failure due to algorithmic instabilities induced by imperfect range measurements. For the TACTICS distributed instrumentation, the calculations are performed in the microcomputer of the Player Pack. This limitation precludes use of the Kalman filter approach on the basis of both computation time in the microcomputer and memory requirements of the Kalman algorithm. The least squares approach was resurrected and modified to handle the nonlinear instabilities using a relatively obscure formalism originally put forward by Marquardt in 1966. This approach was formally adapted to the position-location problem and coded in FORTRAN for experimentation. The formal algorithm works quite well, but is nearly as large and slow as the Kalman filter approach. Additional work, both analytical and empirical, showed that the bulk of the formal algorithm could be deleted for the specific application to the transponder position-location problem. The basic difficulty with the classical least squares technique is that the transfer matrix is not positive definite as a result of the recursion function being nonlinear.

Imperfect range data result in an error function which is cubic (or worse) rather than quadratic. The combination of these effects forces classical techniques to converge to spurious solutions yielding very unstable sequential results and large position-dependent errors. The technique adapted reduces the matrix to simple correlation coefficients among the derivatives of the recursion function which forces it to be symmetric. An additional term, a variable in the formalism but fixed in practice, is applied to make the matrix diagonal dominant which assures that it is always positive definite regardless of the quality of the input data. This in turn guarantees convergence to a stable solution.

The algorithm was coded into FORTRAN and debugged, some slight modifications performed to aid the weighting, and the algorithm was tested. Figure 9 shows the results. These are rather encouraging - the algorithm is quite precise, fast, and robust. Several tests were performed to gauge the impact of errors in the data on the algorithm. The algorithm is very hard to foil, even with data calculated to simulate worst-case errors. As the program closed, the algorithm was being translated from FORTRAN to assembler.

## 6 DEVELOPMENT OF A SIMPLIFIED REAL-TIME CASUALTY ASSESSMENT ALGORITHM.

The primitive real-time casuality assessment algorithm assumes that the probability of a wound or kill relates to the following:

(a) Range between firer and fired upon.
(b) The marksmanship level of the firer.
(c) The weapon used.
(d) The posture of the firer.

The way in which this information relates to the probability of a wound or kill is that inverse range is a good estimator of the probability of a wound or kill as the ratio of the beam size to the bullet path is large. One must work with normalized ranges to translate directly into probabilities. The markmanship level is used to slightly shift the statistics to improve a shooter's score as his marksmanship level improves. The weapon used plays into the calculation because some weapons are more accurate at longer distances than others.

The two weapons that are of interest here are the M-16 and the 357 handgun. Posture too enters the calculation. When, for example, a person is prone he shoots more accurately; if the target is prone it is more difficult to engage.

| TRUE X | TRUE Y | MEASURED RANGES R1 | R2 | R3 | R4 | COMPUTED X | Y | NUMBER OF ITERATIONS |
|---|---|---|---|---|---|---|---|---|
| 10 | 20 | 121 | 81 | 92 | 23 | 9.90 | 19.55 | 3 |
| 15 | 30 | 110 | 72 | 90 | 34 | 15.27 | 29.80 | 3 |
| 20 | 36 | 103 | 67 | 88 | 41 | 19.03 | 35.13 | 2 |
| 25 | 37 | 98 | 68 | 84 | 45 | 24.20 | 36.90 | 2 |
| 30 | 48 | 87 | 60 | 85 | 57 | 30.01 | 48.05 | 5 |
| 35 | 64 | 74 | 50 | 91 | 73 | 35.01 | 63.78 | 3 |
| 40 | 66 | 69 | 53 | 89 | 77 | 39.52 | 65.38 | 2 |
| 45 | 66 | 65 | 57 | 86 | 80 | 44.37 | 65.74 | 2 |
| 50 | 66 | 61 | 61 | 83 | 83 | 49.25 | 65.86 | 2 |
| 55 | 68 | 55 | 64 | 82 | 88 | 54.49 | 68.08 | 2 |
| 60 | 74 | 48 | 66 | 84 | 95 | 59.46 | 72.91 | 2 |
| 65 | 80 | 40 | 68 | 87 | 103 | 64.58 | 79.05 | 2 |
| 70 | 80 | 36 | 73 | 86 | 106 | 69.19 | 80.18 | 2 |
| 75 | 79 | 33 | 78 | 83 | 109 | 74.04 | 79.34 | 2 |

| Tower Positions | T1 | T2 | T3 | T4 |
|---|---|---|---|---|
| X | 100 | 0 | 100 | 0 |
| Y | 100 | 100 | 0 | 0 |
| Z | 3 | 3 | 3 | 3 |

Note: All Data in Meters

Figure 9. Transponder position location algorithm output

The current algorithm solves the following equation:

P(w) = R + M + Pos + Weapon

Where

P(w) is the probability of a wound

R is the range

M is the marksmanship level

Pos is the posture

Weapon is the weapon fired

The result is not a true probability, but an address into a table which contains the probability of a kill. Wounding is not handled at this time.

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